

TITLE

TENSIONED PIPE SUPPORT

5

RELATED APPLICATION

This application is a continuation in part of pending application Serial No. 10/770735 entitled "Apparatus and Method for the Repair and Stabilization of Underground Pipes" filed February 3, 2004, and pending application Serial No. 10/182,889 entitled "Apparatus, Methods, and Liners for Repairing Conduits" and filed February 2, 2001.

BACKGROUND OF INVENTION

15 1. FIELD OF THE INVENTION

The present invention relates to an "insitu" method to repair underground pipes and conduits to reduce or eliminate ground water infiltration while stabilizing the proximate ground formation surrounding the pipes.

2. BACKGROUND OF THE INVENTION

20 The Clean Water Act has mandated that ground water infiltration into our sewer systems be substantially reduced or eliminated. Many methods of repair have been devised over the last thirty years. Some of those repair methods include slip lining, pipe bursting, cured in place pipe lining (CIPP), fold and form thermoplastic lining, spot repairs, as well as the traditional dig and
25 removal/replacement of pipelines.

It is a known fact that the federal interstate highway system has met and in certain cases exceeded its design life by controlling or reducing incidents of pavement collapse, settling and irregular surfaces. This has been achieved with the development of techniques for the injection of grouts or placement of epoxy
30 patches. In addition, the concrete repair industry has developed and refined the utilization of expandable structural closed cell foams to raise, level and stabilize concrete slabs, foundations, pavements and buildings.

The "insitu lining" repair of pipes has been the most effective alternative to pipe "dig and replacement" for many year. Occasionally an existing annular space or void adjacent to the outside surface of the pipe or conduit has been injected with gelatinous grout materials to eliminate water infiltration into the pipe.

5 This repair has been only temporary since the gelatinous material is not dimensionally stabile and often requires later replacement. The grout is not capable of stabilizing the ground around the pipe even if the entire annular space is filled with the gelatinous grout. The lack of stability and support can result in additional stress on the pipe structure, with eventual degradation of the pipe and
10 resulting water infiltration.

Injection of expanding closed cell foams has seldom been used to repair pipes. Where the closed cell foams have been used to level or reinforce pipe sections, there has been migration of the foam into the pipe/conduit joint that, if left in place, can cause an occlusion or blockage. When this migration into the
15 interior diameter of the pipe does occur, a cutting or grinding device must be inserted as a subsequent step to remove the excess foam.

Another issue is the typical foams being used today are polyurethane's which often contain isocyanate, a groundwater contaminant. Some research has been conducted to determine if the closed cell foam chemistry could be used with
20 grout packers. The blowing agents in the foam, however, create a near immediate reaction that will not allow the annular space to be filled with the foam.

There are hybrid polyester/urethanes expandable closed cell foams that could be used and avoid isocyanate. However, these alternate foam formulations have not been well suited to curing in the *ambient* underground soil
25 conditions.

Another method for repair of pipes has been to excavate a damaged pipe section and wrap the outer pipe wall with a high tensile strength material having an elasticity maintaining the band in contact with the pipe. See for example US Patent No. 4,700,752 of Norman C. Fawley. Another method has been to repair
30 or reinforce a pipe section by wrapping the outer pipe wall with a composite material having a multiplicity of high tensile strength filaments encapsulated in a

resin matrix. The wrapping material is manufactured in a coiled structure and installed by deflecting portions of the material into an uncoiled configuration and then wrapping those portions of the material around the pipe. The material may be applied with an adhesive coating on the pipe surface and between each coil
5 layer. See for example Fawley, US. Patent No. 5,683,529 and 5,677,046.

The measure of physical properties of materials relevant to the present invention include ASTM D1621 Compressive Strength, ASTM D790 Flexural Strength, ASTM D1622 Density, ASTM C 273 Shear Strength, ASTM D 2126 Dimensional Stability, ASTM D696 Coefficient of expansion, ASTM D 543
10 Chemical Resistance, and ASTM D 2842 Water Absorption.

SUMMARY OF INVENTION

Insitu pipe repair methods have been developed utilizing techniques for heat assisted cured in place pipe lining ("CIPP") utilizing epoxy repair materials.
15 This technology has allowed the use of styrene free thermosetting or thermoplastic resins in an impregnated ("prepreg") composite repair material that is cured with an expandable and heatable bladder. Thermoset resins are curable resins that can be introduced or impregnated into a fibrous repair material. The curing of the resin results in a change of phase of the resin from a liquid to a
20 solid. As a solid, the repair material continues to have the fiber structure. This technology has been adapted for use in the repair or sealing of pipes or conduits, including sewer mains and lateral lines, ("pipes) and the junctions or interfaces of multiple pipelines.

This invention teaches the use of this technology in combination with the
25 injection of chemical reactants creating expanding closed cell foam ("foaming liquids") for stabilization of the surrounding ground proximate to the underground pipes. The heat assisted CIPP mechanisms and techniques for interior pipe repair thereby allow the use of more environmentally friendly foaming liquids than feasible in ambient conditions to stabilize the ground surrounding the pipe. The
30 inflated bladder can provide a heat source for curing of the resin of the prepreg repair materials, closed cell foaming liquid resin and limiting resin redistribution,

and a supporting mechanism for maintaining the pipe diameter and to prevent infiltration of the foam or foaming liquid into the pipe interior.

The invention also teaches use of the expandable bladder alone within the inside diameter of the pipe in combination with the injection of foaming liquids proximate to the exterior of the pipe surface. The invention also teaches use of an expandable and heatable bladder within the inside pipe diameter to assist in the cure of the injected foaming liquids.

The present invention provides for an improved method of stabilizing the adjacent underground soils or formation around the pipe, minimizing ground water infiltration into the pipe, while repairing the host pipe/conduit or connection. The invention also minimizes exfiltration of sewerage from the pipe. Such exfiltration is a problem particularly when the pipe system is fully charged during a rainfall event.

This invention also teaches the use of an elastically coilable and radially outward expandable material to support and repair pipes. The teaching of this invention includes use for the internal repair of the pipe wall. This may be used in conjunction with other embodiments of the invention such as soil compaction and stabilization using closed cell foam and resin cured pipe wall repair materials.

The invention also teaches use of a exterior tensioned support exerting a radially compressive force that may be used in conjunction with the interior support, an interior inflated bladder, or alone as a heat source combination with heat responsive repair materials.

Other benefits of the invention will also become apparent to those skilled in the art and such advantages and benefits are included within the scope of this invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate preferred embodiments of the invention. These drawings, together with the general description of the invention given above and

the detailed description of the preferred embodiments given below, serve to explain the principles of the invention.

Figure 1 illustrates a typical sewer pipe and lateral connection.

Figure 2 illustrates typical defects necessitating repair of a sewer pipe and
5 sewer pipe connection.

Figure 2A represents a cross sectional view of a defective pipe.

Figure 3A illustrates the prior art use of foaming liquids.

Figures 4A and 4B illustrate the use of the inflatable bladder in combination with injection of foaming liquid.

10 Figure 5 illustrates the pipe repair equipment utilized with simultaneous repair of the pipe interior and ground stabilization.

Figures 5A and 5C further illustrate the pipe repair equipment.

Figure 6C illustrates a detail of the woven repair material for a pipe interface repair.

15 Figure 9 illustrates a woven repair material utilized in one embodiment of the invention.

Figures 10, 10A and 10B are cross sectional views of a hybrid woven repair material.

Figures 11A and 11B are additional cross sectional views of other hybrid
20 fiber woven repair material.

Figure 12 is an illustration of the braided repair material.

Figure 12A is an illustration of a rochelle knit.

Figure 13 is an illustration of the helically wound repair material.

Figure 14 is an illustration of multiply aligned pipe segments.

25 Figure 14A is an illustration of mis-aligned pipe segments.

Figures 15 and 15A illustrate the realignment of pipe segments utilizing the invention.

Figures 16 and 16A further illustrate the realignment of pipe segments utilizing the invention.

30 Figures 17A through 17G provide a cross sectional view of the operation of one embodiment of the invention.

Figures 18A through 18C illustrate cross sectional views of the tensioned support.

Figure 18D illustrates a prior art method.

Figure 19 illustrates the relationship of the pipe surface to the resin
5 impregnated tensioned support with electrically conductive fibers for heating.

Figures 20A and 20B illustrate the combined application of internal and external tensioned supports.

DETAILED DESCRIPTION OF THE INVENTION

10 The above general description and the following detailed description are merely illustrative of the subject invention and additional modes, advantages and particulars of this invention will be readily suggested to those skilled in the art without departing from the spirit and scope of the invention. The teaching of this invention will be understood to be applicable for both the repair or support of
15 sewer pipe connecting interface, as well as for linear and non linear pipelines.

Figure 1 illustrates typical underground sewer pipe configuration that can be the object of repair by the method and apparatus of this invention. The pipes comprise a lateral line **500** typically emerging from a single building or home (not shown). The lateral line is installed for gravity drainage **640** into a collector
20 sewer or sewer main pipe **200** through a connection or connecting interface **400**. Sewerage is gravity conveyed **650** through the diameter **300** of the sewer pipe **200**. The lateral pipe and the main sewer pipe each has a longitudinal axis **350**. However, over time, the orientation of the individual pipe segments may change from the original longitudinal axis, creating a "non linear" pipe. (Reference is
25 made to Figures 14 and 14A.) Non linear pipe can also, of course, include curved pipe.

The lateral pipeline and the main sewer pipe are typically comprised of separate segments jointed by a male-female type connecting end flange. The female flange component **210** and corresponding male component **211** are
30 illustrated in Figure 2. It will be appreciated that the sewer pipe system is buried

within the ground **100** beneath the ground surface **105**. The system can be accessed through various ports such as manholes (not shown).

Figure 2 is a cross sectional schematic of the sewer pipe **200** along the longitudinal axis **350**. The direction of the gravity flow of sewerage is shown by vector arrow **650**. The male **211** – female **210** coupling of the separate sewer pipe sections is also illustrated.

Figure 2 illustrates a common problem experienced with sewer pipe systems. Due do a variety of causes, including the aging of the pipe material, ground shifts or settlement, etc., ground water **175** migrates into the sewer pipes **200**. This can cause the exfiltration of sewerage into the surrounding soil or ground water, particularly when the sewer lines are heavily charged, such as during a significant rain event. Alternatively, the infiltration of ground water can burden the sewerage treatment system thereby increasing treatment costs or causing inadequate treatment. (In addition to the obvious environmental damages that may result from inadequate sewer treatment, the inadequate treatment may result in fines and other damages being imposed by regulatory agencies.)

The infiltration of ground water often carries particles of the adjacent soil **100** into the sewer system, which can over time result in voids **150** being created surrounding the pipe **200**. The creation of voids or increased interstitial spaces results in groundwater collecting proximate to the pipe. This groundwater can then pass, i.e., infiltrate, into the sewer pipe wall **250** through the cracks **240** or holes **255**. It can also pass through defects, such as gaps, in the junctions of each pipe segment **210 211**.

Figure 2A is a schematic illustration across the longitudinal axis **350** of a section of the damaged sewer pipe **200** beneath the ground surface **105** and adjacent void **150** in surrounding soil **100**. Also illustrated are the pipe diameter **300** and cracks **240** and voids **255** through the thickness **251** of the pipe wall **250**. The several vector arrows **175** illustrate the flow of ground water from the soil **100** into the void **150** surrounding the pipe **200** and through the cracks **240** and holes **255** within the sewer pipe wall **250**. It will be appreciated that the

voids intended to be remedied by the subject invention need not be of the large size depicted in these illustrations. Further, it will be appreciated that the subject invention is not limited to repair holes or cracks in pipes, but can be used to seal connections (or "couplings") between pipe segments, or between pipe lines, e.g.,
5 a sewer collection pipe and one or more lateral pipes convey waste ("sewerage") from individual residences, etc.

Use of close cell expandable foams have been used to fill subsurface voids in soils, including use to mechanically raise objects supported by the soil. This has been used in foundation leveling, etc., as taught by Patent Nos.
10 4,567,708, 6,521,673 and 6,634,831. However, this technology has important limitations for use in filling voids surrounding sewer pipes or sealing/repairing pipe defects. One disadvantage is the infiltration of the closed cell foam into the interior pipe diameter (through which sewerage is intended to flow), thereby creating an occlusion that must be mechanically removed to prevent blockage of
15 the sewage flow. In addition, the expansive pressure of the closed cell foam (useful in filling or compacting the soil particles or interstitial voids within the soil or between the underground soil and the structure, e.g., sewer pipe or lateral collector, to minimize water collection/infiltration), may also further damage the pipe wall.

20 Figure 3A is a schematic illustration across the longitudinal axis **350** wherein closed cell foam **600** is injected from the ground surface **105** through the injection mechanism **650** into the void **150** within the ground **100** adjacent to damaged sewer pipe wall **250**. The foam equipment combines static head mixers **650** with a strong insertion device attached to pumps (not shown) located
25 at the ground surface **105**. The cross section view illustrates the closed cell foam filling the void **150** and infiltrating into the diameter **300** of the sewer pipe **200** through the holes **255** and cracks **240** within the pipe wall **250**. The infiltrating foam is shown to create obstructions **337 338 339** within the pipe diameter **300**. It will be appreciated that the foam may not fill the entire void **150**, perhaps due
30 to the presence of entrapped ground water (not shown), thereby allowing for the continued collection of ground water proximate to the repaired pipe. The

migration of foam into the pipe can ultimately block the pipe diameter **300** unless a cutter/grinder unit (not shown) is inserted into the pipe and the occlusion is removed. It will be appreciated that it is desirable to avoid this time consuming and expensive step.

5 One embodiment of the apparatus and methods taught in this specification is the advantageous use of techniques for installing a thermally responsive pipe repair material (thermoset or thermoplastic impregnated liner) within the interior diameter of a sewer pipe *in combination with* injection of expanding closed cell foam proximate to the outer diameter of the sewer pipe. The repair material for
10 the interior pipe diameter may be of a variety of structures, including a structure being defined as an arrangement of fibers such that the repair material has similar dimensions as the pipe diameter or pipe interface to be repaired or sealed. The arrangement of fibers further allows the repair material to be flexible and seamless. Figure 9 illustrates an example of a woven structure **410** having a
15 longitudinal axis **350**. In the illustration, fibers **118 119** intersecting at a variable angle **125**. It will be appreciated that the composition of fibers and fiber architecture can be varied, as shown in the cross sectional illustrations along the axis **AA** in Figures 10, 10A, 11A and 11B discussed later. In a preferred embodiment utilizing the repair material, the material includes a resin having a
20 viscosity. An additive may be provided to alter the resin viscosity. It will be appreciated that it may be advantageous to increase resin viscosity to retard resin redistribution within the fiber repair material or fiber liner prior to and during the installation process.

A flexible and inflatable bladder is inserted within the pipe diameter. The
25 bladder serves as a mold to press and hold the repair material to the interior surface of the pipe during the repair process. The inflated bladder, which, in an alternate embodiment of the invention, can be used without the resin impregnated repair material or liner, also minimize the migration of the chemical reactant or resulting foam injected into the underground soils proximate to the
30 pipe. The migration of chemical reactants or foam can result in occlusion or

obstruction of the pipe diameter. This would obviously hinder the flow of sewerage through the pipe.

The fibrous construction of the repair material, or the components of the inflatable bladder, can include conductive fibers, e.g., carbon fibers, that can be
5 connected to an electrical power source. These conductive fibers, when powered with electric current, may provide electrically resistive or impedance heating (termed herein as "resistive heating") directly through or immediately proximate to the thermosetting resin contained in the repair material. The combined and concurrent pressing of the resin impregnated fibers to the inner
10 pipe wall surface with the heating of the thermosetting resin allows an improved repair and support. The addition of heat, in contrast to ambient conditions, allows more rapid curing. Further, this allows the bladder to remain in place as a mold pressing the repair material for a greater portion of the cure and minimizes the degradation of the repair by resin redistribution. It will be appreciated that the
15 use of the expanding and heatable bladder also minimizes the formation of "annulae" between the interior pipe wall surface and the liner.

Further, heat from the bladder or repair material is also available to radiate through the thickness of the pipe wall to facilitate to the cure of the foaming liquid exterior to the pipe wall. Curing of the foam creates a phase change in the foam
20 to a closed cell solid. The closed cell foamed solid can compact the underground proximate to the pipe, decrease voids or interstitial space containing infiltrating ground water, as well as support and seal the pipe and pipe junctions.

The availability of the proximate heat source also allows use of alternate foaming agents, particularly agents not containing isocyanates. It will be
25 appreciated that isocyanates are considered to be a source of environmental contamination. These alternate reactants include hybrid polyurethane or polyester/polyurethane blend resin, and epoxy resins combined with diluents, catalysts, blowing agents and surfactants, an acrylimide, and cementitious slurry.

Figure 4A is a schematic cross sectional illustration along the longitudinal
30 axis **350** illustrating an embodiment of the method and apparatus of the invention by placing a flexible and inflatable heating bladder **450** inside the pipe diameter

300. The bladder is placed in the area of the pipe having holes 255 or cracks 240 in the pipe wall 250. In this manner, the inflated bladder can provide support to the damaged pipe and facilitate maintaining the pipe diameter 300 during the repair process. The bladder may have resistively heatable sub-components to
5 facilitate the curing of the chemical reactant injected proximate to the exterior pipe wall surface 254.

Figure 4B is a schematic illustration across the longitudinal axis 350 of the pipe after inflation of the bladder 450. The bladder, if used as a heat source, may assist in the curing of the closed cell foam. It will restrain the injectible
10 chemical reactant and resulting foam 600 from permeating the pipe through coupling connectors (211 210 of Figure 2) or cracks 240 or holes 255 in the pipe wall 250. The migration of foam is illustrated in Figure 3A by the multiple vector arrows. The liner 410 (not shown) may be placed over the bladder for reinforcement or to minimize binding of the bladder to the cured foam.

15 An embodiment of the invention includes the use of resistive energy as a source of heat for curing the injected chemical reactant, as well as to block the migration into the pipe diameter. This heat curing can be accomplished in combination with the placement of a resin impregnated ("prepreg") repair material within the pipe diameter. As mentioned above, the repair material or the flexible
20 bladder may contain electrically conductive fibers. Alternatively, the fiber can be a combination of electrically conductive fibers and non-conductive fibers, which include polyester, glass, aramid, and quartz fibers, and thermoplastic fibers such as, but not limited to polypropylene, nylon and polyethylene.

The repair process is illustrated in Figures 4A, 4B and Figures 17A-G
25 where one skilled in the respective arts observes that there are similarities in both systems, which require 50 K.W. generators and 150 CFM compressors and various cables and hoses. The present invention demonstrates the synergies between the two systems, which eliminates boiler trucks, and on site mixing and impregnation of repair material.

30 An alternative embodiment that can be used alone or in conjunction with the bladder is inserting an elastically coilable and radially expandable material.

This can be of differing materials, including metal. Important features will be the elasticity, high strength and shape memory, thereby allowing the material to be wound into a tighter coil with a more compact diameter or shorter radius and expansively returning to its original shape. Upon release of the winding energy,
5 the material relaxes and returns to its original coil diameter. This relaxed diameter will be greater than the internal pipe diameter, thereby causing a relative uniform radial outward pressure force.

It will be appreciated that the mechanism will maintain an open annulus within the pipe thereby allowing the continued passage of fluids through the pipe.
10 Of course this can permit the relaxed coil to remain in place during the curing process, and thereafter without interruption of service.

This invention addresses the cause and repair of connection offsets or misalignment of pipes and conduits. The misalignment of an originally installed linear pipe may result from faulty bedding surrounding the pipe, which is not
15 tested as it is in pressure pipe/conduit situations, and ultimately can crack or offset the joints after the pipeline is back-filled. Another cause of misalignment is the result of the movement of ground water as already discussed. While some may contend this method is redundant and more costly, one skilled in the art will easily recognize the efficiencies and safety elements of the present invention

20 This embodiment of the invention provides methods of repairing the misalignment of pipe sections **250A** such as that shown in Figure 14A. In this case, the non-linear conduit is buried below the ground surface **105** predominantly in a horizontal orientation as part of a pipe network, e.g., sewer system. The non-linear pipe consists of separate pipe or conduit segments **25A**,
25 **25B**, **25C**, **25D**, **25E**, **25F**, **25G** that have moved from the original longitudinal axis **350** illustrated in Figure 14 to a non congruous longitudinal orientation **351** and thus does not follow a strictly linear path.

The embodiment of the method taught by this invention comprises providing the inflatable bladder dimensioned to fit within the interior diameter **300**
30 of the pipe **250A**, and particularly each non-congruous pipe segment **25A**, **25B**, **25C**, **25D**, **25E**, **25F**, **25G**. The bladder is dimensioned so as, when inflated,

presses against the interior surface of each damaged, e.g. mis-aligned, cracked or broken, section of conduit. The bladder can be made of any strong flexible material. It will be appreciated that it may be advantageous to fit the bladder with one or more layers of protective outer sleeves or liners ("liners"). The liners can provide a repair material (sometime referred to as "material structure") as discussed elsewhere herein, but may also provide protection to the bladder from sharp or jagged surfaces within the conduit sections. The bladder may be filled/inflated with fluid, such as water or air, and the effectiveness of the bladder would be compromised if the bladder was punctured.

Figure 15 and 15A illustrate an embodiment of the invention wherein the bladder **450** is placed within the diameter **300** of several mis-aligned pipe segments **25A, 25B, 25C, 25D, 25E, 25F, 25G** beneath the ground surface **105**. Figure 15 illustrates the bladder with several pipe segments **25B 25E** removed for clarity of illustration. The original or intended longitudinal axis of orientation **350** is also shown. It will be appreciated that the mis-alignment may be in any of the three axes of orientation (X, Y, Z).

Figure 16 illustrates the next step of the repair method. Multiple chemical reactant insertion ports **650** are installed from the ground surface **105** to a desired location proximate to the pipe. In the illustrated situation, the ports are installed to be beneath the mis-aligned pipe segments **25B, 25C, 25D, 25E, 25F**. The goal of the repair is to push the pipe segments into closer alignment with the longitudinal axis **350**. A chemical reactant is injected through the ports into the ground **100** creating the expanding foam **600**. Figure 16A illustrates the result of the injection of expanding thermosetting foam **600**, causing pipe segments **25B, 25C, 25D, 25E, 25F** to be pushed upward as shown by vector arrow **675**. The inflatable bladder **450** acts as a flexible mold having a control or guiding function in the realignment of the pipe sections, particularly with regard to the continuity of the pipe diameter **300** and common longitudinal axis of orientation **350**.

As suggested by the Figures 14 through 16A, substantial length of pipe can be simultaneously repaired by the invention. The length of inflatable and heatable bladder is not limited. Lengths of pipe extending from one access

manhole to a second manhole may easily be simultaneously repaired by a single use of the method and apparatus of the invention.

Based upon the foregoing disclosure, it will be readily appreciated that the above method can be combined with the embodiment utilizing a repair material
5 liner impregnated or containing a curing thermosetting or thermoplastic material to seal the pipe from the interior diameter. The repair material structure may be defined by a plurality of fibers such that the repair material is flexible and seamless. This structure is sometimes referred to as a woven "preform".

Thee resin may be in the form of prepreg fibers or as a resin matrix
10 surrounding the woven structure. The resin can be a polyester resin, a vinylester resin, a urethane polyester resin, a urethane-vinylester resin, an epoxy resin of a polyurethane resin. The resin is introduced into the repair material by either injection of infusion depending on the type of resin utilized.

A flexible and seamless repair material is able to adapt and conform to of
15 the interior repair material will neither bind nor wrinkle to cause obstructions to material flow in the conduit. The construction and selection of the repair material also allows it to be used in conjunction with the inflatable bladder. The repair material may be placed as an outer liner on the deflated bladder.

Next, the repair material and bladder is placed in the conduit in close
20 proximity to a damaged portion of the conduit. As the bladder is inflated, the repair material is pressed against the inner surface of the conduit wall. Finally, the resin is cured. Curing can be achieved in a number of ways, including but not limited in using hot water, steam, resistive heating, or infrared and ultraviolet radiation.

25 Preferably the material structure **410** is substantially cylindrical (as shown in Figures 9 and 13) to facilitate conformity with the non-linear conduit. The cylindrical structure has an interior diameter **301** oriented about a longitudinal axis **350**. However, the material structure is flexible and can be formed by braiding the fibers. A repair material **410** having a braided configuration of fibers
30 **411** is shown in Figure 12. In braiding most, if not all, of the fibers **118 119** are arranged in a helical pattern (as shown in Figure 13). However, triaxial braiding

can be used to combine fibers at two different axial or helical angles with a non-helical, longitudinal fiber. Repair materials fabricated by braiding processes offer exceptional ability to conform to irregular conduit geometries. Because a braided repair material is formed with its reinforcing fibers positioned helically rather than perpendicularly to the longitudinal axis of the material structure, these fibers have the ability to change their braid angle **125**, and conform simultaneously in both the inside radius and outside radius of a section of a non-linear conduit.

Depending on the desired mechanical properties the density of the fiber braid can be varied to pack more fibers into the tubular arrangement to provide an increase in strength. Conversely, if the structural requirements are minimal, the braid density can be adjusted to where the material present in a volumetric area can be reduced. The angle **125** at which the fibers intersect each other, otherwise known as the braid angle, can also be varied. When the braid angle is increased, the fibers are positioned closer to perpendicular or vertical and the hoop strength of the finished repair material increases. This is desirable for conduits that are required to support a great amount of weight or withstand high internal pressures. The varying mechanical fiber compaction can be used, e.g., knitting, weaving and braiding.

Use of braid or similar types of mechanical fiber compaction construction also will facilitate the unlimited lengths of pipe that may be simultaneously repaired.

Figures 10, 10A, 11A and 11B are cross sectional representations of the fiber layers of a repair material illustrated in Figures 9 and 13. Various reinforcing materials can be included in the braided construction to accommodate both performance and cost issues. Figure 10 illustrates a combined placement of reinforcing fibers **122**, e.g. glass or nylon, with fibers **124** constructed of thermoplastic material. These fibers can be one of a combination of various engineered thermoplastics. In addition, thermoplastic films **130** may be used. These fibers, films and reinforcing fibers can be consolidated using any of the aforementioned methods. Figure 10A illustrates repair material **410** comprised of a combination of reinforcing fibers **122** impregnated within a matrix of resin **131**.

Various non-electrically fibers can be employed as reinforcement. The fiber construction can be varied as shown in Figure 11A. The combination of fibers forms the material structure **410**. Additionally Figure 11A also shows a film **130** of thermoplastic material that forms part of the material structure **410**.

5 Additionally, Figure 11B illustrates that the material can include electrically conductive fibers **120**, for example carbon fibers, in order to cure the resin and electric current can be caused to flow through the conductive fibers to resistively heat the repair material. The fibers can be a combination of electrically conductive fibers **120**, thermoplastic fibers **124** and non-conductive fibers **122**
10 e.g., polyester, glass, aramid, and quartz fibers. Other combinations and architectures will be apparent to persons skilled in the art.

When electrically conductive fibers are used in conjunction with the thermoplastic fibers and films, as illustrated in Figure 11B, resistive heating can be generated. The heat causes the thermoplastic materials to melt and flow,
15 permeating the electrically conductive fibers and other non-electrically conductive fibers. A reinforced thermoplastic composite results when the materials cool and harden. In this embodiment, the need for liquid thermosetting resin (which phase change solidification may be enhanced by the addition of heat) is eliminated offering unlimited shelf life and ease of handling. Finished composite properties
20 can be customized with the selection of an appropriate thermoplastic matrix and reinforcing fibers.

As shown in cross section in Figures 10 and 11A the repair material can contain fibers having both structural properties **122** and thermoplastic fibers **124**. Alternatively separate bundles of electrically conductive fibers **120** can be co-
25 mingled with bundles of thermoplastic fibers **124** and structural or reinforcing fibers **120** as shown in Figure 11B. In both cases, the bundles may be braided together to form the repair material.

In another preferred embodiment, the electrically conductive fibers have an exterior layer or coating of electrically conductive fibers than are then braided.
30 In another preferred embodiment, the seamless material structure is formed by knitting the fibers. In knitting, the repair material is produced by inter looping

continuous chains of fibers in a circular fashion. An enlarged view of knitted fibers **118 119 120** is shown in Figure 12A. In a rochelle knit, it is possible to introduce the fibers in a basically longitudinal direction. Because the fibers **118 119** are looped in a circular fashion at every stitch, the finished tubular structure is inherently flexible. For example, in one linear inch of fiber stitch, the actual fiber length may be as long as two inches. This allows continuity in the fibers throughout the length as well as allowing the fiber loops to stretch or open up to variances in the conduit geometry. Various reinforcing materials can also be included in the knit construction to accommodate both performance and cost issues. In addition, electrically conductive fibers **120** can be used such that resistive heating is feasible to cure the resin.

In another preferred embodiment, the seamless material structure is formed from a combination of two or more material layers. A first material layer is a seamless, cylindrical tube configured to fit within a second material layer that has a seamless, cylindrical tube configuration. The material layers are formed from an arrangement of fibers, preferably either braided or knitted fibers. The first material layer is nested within the second material layer and then stitch-bonded together with a stitching thread to form the materials structure. Preferably, the stitch-in thread is elastic to further ensure flexibility of the repair material. In addition, electrically conductive fibers can be used such that resistive heating is feasible to cure the resin.

Stitch bonding is a method by which different materials can be consolidated into various forms including seamless, tubular products. The consolidating results from either continuous or intermittent stitching or sewing through the various layers materials. Reinforcing fibers can be used and aligned in a helical arrangement to accommodate geometry changes much like a braided composite. Stitch bonding also allows the use of a wider variety of electrically conductive material formats such as non-woven graphite formed into tapes. These tapes would be introduced into the composite at a helical angle.

In another preferred embodiment, the seamless material structure is formed from a combination of two or more material layers. A first material layer

is a seamless, cylindrical tube configured to fit within a second material layer that also has a seamless, cylindrical tube configuration. The material layers are formed from an arrangement of fibers, preferably either braided or knitted fibers. The first material layer is nested within the second material layer and then needle
5 punched with a needle board to form the material structure. The needle board has a plurality of needles such that the needles penetrate the first material layer. When needles are driven through the first material layer, varying amounts of fibers from the first material layer are pulled through the cross section of the adjacent second material layer. These fibers effectively bind the material layers
10 together. In addition to consolidation, the fibers also provide reinforcement in the Z axis, defined as the axis corresponding to the material layer thickness. The characteristics of the repair material, including flexibility, can be altered by varying the force applied to the needle board, the type and number of needles used, and the number of needle penetrations per square inch. In addition
15 electrically conductive fibers can be used such that resistive heating is feasible to cure the resin.

In another preferred embodiment, an additive adapted to increase the resin viscosity is provided. The additive is mixed with the resin to form a resin-additive mixture whereby the resin viscosity is increased after a period of time
20 has elapsed. The additive should be formulated such that the resin viscosity does not immediately increase because this could preclude either resin introduction or resin permeation of the repair material. The resin additive adheres to the fibers in the first and second material layers. As a result, the resin additive mixture stabilizes the fibers and the material layers. In addition
25 electrically conductive fibers can be used such that resistive heating is feasible to cure the resin.

Figures 17A through 17G illustrate the sequential steps of the combined application of curing a foaming chemical reactant proximate to the exterior of underground **100** pipes, with placement of a curable liner on the interior pipe
30 surface. Figure 17A is a cross sectional view of a pipe **250** beneath the ground surface **105** and having an interior diameter **300**. The pipe has a longitudinal

axis of orientation **350**. The pipe has an inner wall surface **256**, an exterior wall surface **254** and a wall thickness **251**. Also illustrated is an insertion port **650** for injecting expanding foam reactant at a selected location in relation to the buried pipe. Also shown is the deflated bladder **450** and separate material structure **410** positioned as an outer liner to the bladder.

Figure 17B illustrates the same components within the ground **100**, but with the bladder **450** now inflated and placing the material structure/repair material **410** into near contact with the inner pipe surface **256**. The diameter **301** of the material structure is shown. In this cross sectional view, only a small portion of the original pipe diameter **300** is not occupied by the inflated bladder and material structure.

It will be appreciated that the bladder **450** is to be inflated to press the structural material **410** into contact with the inner pipe wall **254** and the space shown in the following Figures is for clarity of illustration only.

Figure 17C illustrates the foaming chemical reactant **600** being injected into the ground **100**. The foam variously expands in all directions, as illustrated by the several vector arrows, creating a force compacting the underground soil, driving away interstitial groundwater and pressing against the outer pipe wall **254** now *reinforced by the inflated bladder 450*. Figure 17D illustrates this process with multiple injecting foams, causing the pipe to be substantially encased in the expanding foam **600**, thereby compacting the ground, driving interstitial groundwater, minimizing or filling voids adjacent to the pipe and thereby stabilizing the pipe.

Figure 17E illustrates the curing of the foam assisted by electrically resistive heat created from current within the electrically conductive fibers within the repair material **410**. A portion of the radiating heat travels outward into the thickness of the pipe wall **251** and into the surrounding ground or foam. The distance or range of significant heat transfer **605** may be less than the area occupied by the foam **600**. However, within this area **605**, effective curing of the foam can be achieved, thereby effectively encapsulating the pipe wall, while simultaneously installing an interior reinforcing material. (In another embodiment

discussed previously herein, the conductive fibers can be contained within the bladder or a protective liner of the bladder separate from any repair material.)

Figures 17F and 17G illustrate a cross sectional area of the invention, illustrating the interior diameter **301** of the repair material **410** containing the inflated bladder **450**, the pipe thickness **251**, the area **605** of foam cured by the radiant heat, the outer area of foam **600** and the surrounding ground **100**.

The present invention also provides methods and apparatus for repairing a section of non-linear pipe such as the junction or interface **400** between two pipes **200 500** as illustrated in Figure 1. A preferred embodiment of the apparatus of the present invention is depicted in Figure 5. In accordance with the invention, the apparatus includes a main body **460** that is positioned in a first conduit **200**. The first conduit **200** may be pipe forming a main line of a sewer system. The main line **200** intersects a second conduit or lateral line **500**. Lateral line **500** is shown here in a perpendicular position essentially at a 90 angle to the main line pipe and intersects the main line pipe at the top portion. This condition is typical but may also be arranged in other configurations. For example, the lateral pipe may intersect the main line pipe at $\pm 45^\circ$ and can be located radially anywhere from the nine o'clock position to the 3 o'clock position.

Radial and vertical positioning of the apparatus is achieved remotely using appropriate controls, and communicated to the apparatus through an umbilical **350**. The entire assembly **460** is delivered to the point of repair using a winch or similar device (not shown) attached to the unit via cable assemblies **345**. Also illustrated are the heatable caul plates **465** and the flange portion of the repair material **411**. (It will be appreciated after reading the following paragraphs that Figure 5 illustrates the repair material in a loaded position within the main body **460** of the apparatus.

Figure 5A provides a cross sectional view of the apparatus depicted in Figure 5, showing the heatable caul plates **465** in a retracted position on an upper portion of the body **460** of the apparatus, thereby affording a minimal cross section and allowing passage into a main line that may contain offsets,

protrusions, etc. The caul plates **465** (hereinafter referred to as "wings") are articulated to allow this reduced cross section by the use of hinges **466**.

Figure 5A illustrates the loading of the repair material **410** into the apparatus **460** in preparation for insertion at the intersection of the main line and lateral line. Repair material **410** is preferably constructed of a fibrous woven material capable of holding a heat hardenable or formable resin matrix. Material **410** is also constructed of a material that would be expected to include a portion **412** that conforms to the interior geometry of the lateral pipe wall, and be flexible enough to provide a flange face **411** in the main line pipe. (Reference is also made to Figure 6C.) It is shown that the repair material is wrapped around the retractable/inflatable bladder segment **440**. In 5C, the method for loading the repair material **410** is also illustrated. Applying a fluid pressure to the body **460** through umbilical **350** pressurizes an inflation device in the form of a bladder **440**. This fluid pressure is regulated through the use of electro-pneumatic regulators located in rear housing **461** in the body **460**, and controlled remotely through signal wires in umbilical **350**. Pressure sensing is accomplished by sending units located within main body and transmitted through umbilical. All of the signal wires in the umbilical terminate at an operator interface control station (not shown). The force required during this step is minimal and sufficient to cause the bladder **440** to rigidize.

The repair material is constructed in such a fashion as to incorporate both the tubular lateral lining portion **412** as well as the flanged area **411** without the undesirable effect of a potentially weak seam at the transition from tubular to planar. With the bladder **440** pressurized, the material **410**, which may be pre-impregnated with a resin as described elsewhere in this specification, is wrapped **412** around the extended bladder **440** as shown by the vector arrow **676** and caused to lay flat **411** on the surface of the wings **465**. Depending on the structural requirements, layers of material can continue to be plied to achieve the desired strengths. With the lay-up complete, the pressure of the bladder **440** is lowered the material **410** can be inverted into the main body of the apparatus as shown in Figure 5C. The main body contains a spindle **453** capable of rotation

that is fixably attached within the body **460** at a posterior location. The spindle is sealed from the atmosphere to the use of o-rings and protrudes slightly from the body to allow attachment of a tool to cause rotation.

As shown in Figure 5D, the bladder construction contains an internal
5 tether **451** that is permanently attached to the interior of the bladder at fitting and removably attached to spindle **453** within the main body **460**. To invert the bladder **440** and repair material **410** into the main body for safe transport to the repair location, the tether is wound about the spindle causing the bladder to retract. With the repair material loaded into the device, a winch, or similar device
10 is employed to pull the apparatus to the desired location within the pipeline. A closed circuit television camera (not shown) can be used to assist in determining the correct location and positioning. Once the entire assembly has been satisfactorily located in proximity to the repair area, final positioning commences via remote control.

Figure 5D shows the internal working of the apparatus. In order to
15 facilitate rotary position, the apparatus contains a powered rotation mechanism located in the rear housing **461**. The rotational mechanism is attached to the main body by use of a coupling. The front section **462** of the body **460** contains a rotary bearing to compliment this action. Skids **472** are attached to both the
20 front **462** and rear **461** sections to afford minimal surface contact with the main line pipe and ease pulling forces required.

Figure 5D illustrates the apparatus used for placement of the flexible
bladder **440** at the pipe interface section **400**. The apparatus is positioned in radially and longitudinally within one pipe **200**. The lift cylinders can be elevated
25 by hydraulics or compressed air using a suitable medium. The lift cylinders are firmly attached to the front section **462** and rear section **461** with cylinder rams attached to the main body. When activated, cylinders **473** effectively lift the main body to force the top portion of the caul plate **465** to be in contact with the interior wall of the main line pipe at the area surrounding the lateral pipe opening. As the
30 main body lifts, actuator arms **474** encounter the main line pipe wall, as depicted in Figure 5D and 5E. In Figure 5E, the actuator arm bearings **474** convert the

vertical motion to a lifting motion through a fulcrum attached to the main body. The opposite ends of the actuator arms are positioned under the wings **465** and cause the wings to unfold and compress the flanged area **411** of the repair material firmly against the main line pipe walls.

5 By introducing pressure to the interior of the main body through umbilical, the bladder and repair material is caused to invert into the lateral pipe. Increasing the pressure inside the bladder causes the tubular section of the repair material to conform to the inside geometry of the lateral pipe section.

10 The bladder and the caul plates may be constructed of a temperature resistant material and contain within the outer skin surface, electrically conductive fibers that are employed to produce heat when an electrical current passes through the fibers. The material surrounding the conductive fibers is a flexible, resilient substance such as silicone, fluorosilicone or fluoropolymer. Electrical wires conduct the electrical energy from remotely stationed,
15 controllable power supplies to the electrically conductive fibers. Heating temperatures may be produced range between 200 F to 400 F depending on the cure requirements of the resin matrix selected for use in the repair material. These temperatures can be achieved in as little as 10 minutes enabling an extremely fast cure cycle.

20 In conjunction with the inflation of the bladder into the interior diameter of the pipe interface and the heating of the bladder and caul plate, reactants can be injected into the ground proximate to the interface to compact the soil and stabilize the soils adjacent to the pipe similar to the manner discussed earlier in regard to Figures 2 through 4B above. The inverted bladder thereby also serves
25 to minimize the infiltration of injected reactant or reaction product into the interior diameter. Further, it will be readily appreciated that the heat of the bladder, caul plates or liner may be available to radiate through the thickness of the pipe wall to facilitate the cure of the injected reactant. Again, this heat source may also allow the use of reactants that are not effective in the ambient subsurface
30 environment.

An alternate method and apparatus to the inflatable bladder is the utilization of a radially expanding interior support. The support taught by this specification utilizes a tensionable and compressible coil. The coil possesses a memory of its original coil radius. After the compressive means are removed, the coil returns ("relaxes") to its original radius. This characteristic is a property of material elasticity. When subjected to a stress, e.g. tensile or compressive, the dimensions of the material change, i.e., strain. For an elastic material, the strain is recovered when the stress is removed. When properly dimensioned, as taught herein, the interior pipe wall surface retains the coil in a partially tensioned
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stated, with a residual outer pressing force. This force, like the outward pressure of the inflated bladder, can be used to form a repair liner or surface patch within the pipe. Unlike the bladder, the coil does not impede the flow of liquid through the pipe and can remain in the pipe as a structural support element, as well as a mechanical means to press and cure repair materials such as thermosetting or thermoplastic materials. It can also block the infiltration of injected reactant, or the resulting cured closed cell foams that are also taught by the invention.

The coil apparatus can be constructed in various forms. One embodiment may utilize a resinous plastic material having sufficient elasticity to allow compression without permanent deformation of shape. The material may be
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constructed to also include electrically conductive fibers or wire that can be connected to either a dc or ac power source to provide resistive or impedance heating (generally termed resistive heating herein). As already discussed herein, the heat may be utilized in curing or shaping thermally responsive materials that may be used in conjunction with this invention.

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The coil support structure may also have a fibrous structure that may be impregnated with resinous thermal responsive materials. These materials may be thermal plastic or thermal setting resins. In the case of thermal setting materials, the ability to provide heat while in a pressed state to the interior pipe wall may shorten the repair cycle. It may also provide for improved repair by
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minimizing voids between the pipe wall and the material caused by shrinkage during the material cure or setting.

The material may utilize ester or epoxy resin systems that are allowed to partially cure, preferably to a B stage, without significant cross-linking, prior to release of the tension coil energy. At this partially cured stage, the impregnating resin remains malleable to conform to the vagaries of the interior surface of the pipe wall. This will minimize voids or undesired annular spacing remaining between the relaxed support surface and the interior pipe wall. It will be appreciated by persons skilled in the art that a B stage cured resin is at a highly viscous state, substantially able to retain a shape, but sufficiently plastic to be malleable to the irregularities of a contacting surface. As curing progresses to a C stage and to final cure, cross linking of the polymer molecules increases and thereby creating increasing rigidity of the material, resulting in a solid material at completion.

The support structure may also incorporate multiple layers of reinforcement material combined together as a single layer coiled within the interior with minimal overlap (as illustrated in Figure 18B). The multiple layers may be attached by needle punching or mechanical means. Lateral movement of the layers as a result of the coiling process may be contained by the mechanical intra-laminar attachments, thereby enhancing the shape memory, i.e., the recovery of the shape after removal of the stress or tension force. The support structure may also utilize adhesive properties or materials to bind to the pipe wall.

Figure 18A illustrates a cross section of a pipe **250** having an interior diameter of D_2 . Figure 18B illustrates a flexible coil **480** having an outer diameter of D_1 that is larger than the interior diameter of the pipe. Figure 18C illustrates the flexible coil wound into a tighter coil with a new diameter D_3 . This second diameter, achieved by the tighter winding of the coil, is smaller than the first diameter and the interior diameter of the pipe. This relationship can be expressed as $D_1 > D_2 > D_3$.

Figure 18D illustrates a prior art method of pipe **250** repair utilizing a tensioned coil **499** that is wrapped around the *exterior* of the pipe. The method utilizes wrapping a multi-layered coil having a radius smaller than the exterior

diameter of the pipe. The coil material possesses memory of its first coil radius. It there for tends to adhere closely to the outer surface of the pipe (the circumference of the pipe having a larger radius than the first radius of the coil). Of course, the coil can only be wrapped around a pipe having a 360° exposed surface. This would require a buried pipe to be excavated for application of such a coil wrapping.

Figure 19 illustrates a cross section view of a coil **480** in relation to the interior surface **256** of the pipe. Also illustrated are electrically conductive wires or fibers **122** that are surrounded by a B stage ester or epoxy resin matrix **130**. The shape memory properties of the coil material matrix cause the outer coil surface **481** to press the resin matrix to the inner pipe surface as shown by vector arrow **640**. Also illustrated is a tension support substrate **132** that may comprise a resinous plastic material or a metal or combination of both.

Another embodiment of the invention subject of this specification teaches utilization of internal support with the exterior wrapped tension coil support to create an interior and exterior walled mold. A defect cavity enclosed within the walled mold or "form" can be then injected with repair material. In one embodiment, the repair material can be injected closed cell foam creating chemical reactants. The reactants will be maintained under pressure within the form, thereby creating enhanced density of the foaming reaction products. The pressure or material strength of the repair mold is attributed to the combination of material strength and the tensioned architecture.

Figure 20A illustrates a cross sectional view of across the longitudinal pipe axis **350**. Figure 20B illustrates a cross sectional view of one section of pipe wall along the longitudinal axis **350**.

Figure 20A shows the pipe wall **250** having a inner surface wall **256** and an outer surface **254**. Within the pipe annulus **301**, the tensioned coil **480** support is released and allowed to unwind, resulting in the outer surface of the support pressing radially outward in the direction of the vector arrows **640**. It will be appreciated that the radially directed force applied to the inner pipe surface **256** will be substantially uniform around the circumference of the pipe.

The outer surface of the tension support may be coated (not shown) with an adhesive or thermal responsive material, e.g., thermal setting, thermal plastic or a resin chemical reactant. Alternatively, the support material may impregnated with such components. As described elsewhere herein, the tensioned support
5 may also incorporate electrically conductive materials for heating. The outer pipe wall surface **254** is tensioned wrapped with a material **299** similar to the internal tensioned support, i.e., an elastic material with a matrix memory resulting in it contracting to its relaxed radius (being smaller than the radius of the outer pipe wall). The inner surface of the outer wrap, placed in contact with the outer pipe
10 wall, may also have an adhesive coating or coating of a thermal responsive material. The outer wrap also will have a radially inward compressive force illustrated by the vector arrows **641**. This compressive force will also be substantially uniform around the circumference of the pipe **250**. The outer wrap may also contain electrically conductive materials for heating. The pipe wrapping
15 action is indicated by vector arrow **643**. The outer wrap may also have one or more inlets **498** through which expansive foaming chemical reactants may be injected. It will be appreciated that the gap or space shown in Figure 20A between the pipe and each tensioned support is for clarity of illustration only and that the surfaces will be in close contact.

20 Figure 20B illustrates a cross sectional view of the pipe **250** along the longitudinal axis **350**. The inner tensioned support **480** is shown in contact with the inner pipe wall **256**. The surface interface **484** may contain a coating or thermal responsive material. The outer wrapped tension support **499** has a similar interface **497** with the outer surface **254** of the pipe wall **250**. Figure 20B
25 also illustrates a hole or defect **255** in the pipe wall that is contained with the tension inner and outer supports. This void or "repair cavity" **255** may be filled by material injected through the injection port **498** via a pipe or hose **605**. The inner and outer tensioned support will have sufficient strength to contain the foam reactant. Due to the confined fixed volume of this repair cavity, the injected
30 reactant (not shown) may achieve increased density that if permitted unrestricted expansion.

While specific embodiments have been illustrated and described, numerous modification are possible without departing from the spirit of the invention, as the scope of protection is only limited by the scope of the accompany claims.

5 This specification is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the manner of carrying out the invention. It is to be understood that the forms of the invention herein shown and describe are to be taken as the presently preferred embodiments. As already stated, various changes may be made in the shape, size and arrangement of
10 components or adjustments made in the steps of the method without departing from the scope of this invention. For example, equivalent elements may be substituted for those illustrated and described herein and certain features of the invention may be utilized independently of the use of other features, all as would be apparent to one skilled in the art after having the benefit of this description of
15 the invention.

Further modifications and alternative embodiments of this invention will be apparent to those skilled in the art in view of this specification.